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ACOUSTIC EMISSION FROM BERYLLIUM

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Abstract

ACOUSTIC EMISSION FROM BERYLLIUM

The acoustic emission from both powder and ingot source beryllium has been measured as a function of strain and prior heat treatment. Most measurements were made during tensile deformation, but a limited number of compression tests have also been performed. The acoustic emission observed was of the burst type, with little or no contribution from continuous type emission. The emission was characterized by the variation of burst rate and average energy per burst as a function of strain. The tensile behavior was qualitatively similar for all the materials tested. Burst rate maxima centered roughly at 0.1 percent and 1.0 percent plastic strain were observed. The magnitude but not the strain at the low strain burst rate peak was very sensitive to prior thermal treatment, while the higher strain burst rate peak was insensitive to prior heat treatment. An energy per burst maximum was observed at 0.2 percent plastic strain, the magnitude of which was moderately sensitive to heat treatment. The Kaiser effect is observed in the material studied. Emission during compression was similar to that observed in tension. The acoustic emission observed is attributed to dislocation motion, as proposed by James and Carpenter for LiF, NaCl, and Zn. Metallographic studies of the beryllium at various strains have ruled out microcracking and twin formation as major contributors to the acoustic emission.

ACOUSTIC EMISSION FROM BERYLLIUM

INTRODUCTION

Acoustic emission is a transient elastic wave generated by the rapid release of energy within a material. The elastic waves generated during deformation can be audible in some materials, notably tin, but generally the frequencies of the waves are greater than audio frequency. The mode of propagation and small amplitude of these waves require a transducer and substantial amplification for their detection. Acoustic emission has been studied in a large number of materials and is being used to detect and to locate growing flaws in structures both in service and during proof tests. A number of reviews of acoustic emission have been published.⁽¹⁻⁴⁾ The work described here was undertaken to characterize the acoustic emission from beryllium during deformation and to identify the mechanism or mechanisms responsible for the emission. The results can be used to help interpret the acoustic emission from beryllium structures during proof testing.

Experimental Procedure

The acoustic emission system used was made from Dunegan Endevco (D/E) modules. The output from a D/E S140 transducer (PZT-5A piezoelectric type, sensitive to longitudinal waves, resonant frequency 140KHz) coupled to the sample with a viscous resin was fed through a Model 802P preamplifier into two Model 301 totalizers with frequency bandpasses of 100-300 KHz. Certain experiments were also conducted with a S 750 transducer and a high

pass filter, lower cutoff 100 KHz. Total gain of the system was 85db (17,000X). The character of the signal was observed during the tests with a transient wave recorder and oscilloscope. RMS acoustic emission output voltage was measured with a Hewlett Packard 3400A RMS voltmeter.

Burst emission was evaluated with a D/E Digital Envelope Processor which gives a continuous summation of the number of bursts observed during the tests. From this summation an average burst rate was obtained for each 30-second interval throughout the test. A D/E Energy Module was used to obtain a measure of the average energy per burst. This device squares the RF signal from a burst, and feeds the squared signal to a voltage controlled oscillator. The number of counts from the oscillator during the burst is then proportional to the true-mean-square of the signal. The output of the oscillator is summed and the average number of counts from the voltage controlled oscillator per burst calculated for 30 second intervals. These values will be referred to as average energies per burst. The energy per burst is a relative measurement, and will depend upon specimen geometry, material, transducer placement and system gain as well as the actual energy released by the event responsible for the acoustic burst. If the former variables are held constant, then changes in measured energy per burst with strain or with different material treatment should reflect changes in the energy released by emission events. No completely satisfactory technique has been devised to relate the measured energy per burst to the actual energy release within the material. We have devised an approximate calibration technique to estimate the proportionality

constant between the relative energy scale and absolute energy which also provides information about the effect of specimen geometry. The calibration involves measuring the energy of bubbles bursting on the sample surface with the acoustic emission equipment, and relating the measured energy to calculated energy release from a bubble burst. The calibration is described in detail elsewhere.⁽⁵⁾

Beryllium from three suppliers was studied. Powder source beryllium conforming to Rocky Flats specification P-31664 was obtained from both Kawecki Berylco Industries and Brush Wellman. This beryllium grade is similar to KBI grade HP-10 and Brush-Wellman grade S-240. It is used because of its good high temperature ductility and formability. The chemistry, mechanical property, and grain size requirements for this specification as well as measured properties for the materials studied are given in Table I and Figure 1. Samples from ingot source beryllium fabricated at Rocky Flats Plant were also tested. Typical chemistry and mechanical properties for the ingot source beryllium tested are given in Table II. The materials studied came from a large number of hot pressings and ingots.

The beryllium was tested both as received and after a number of thermal treatments. Both powder source suppliers sintered the virgin beryllium powder into logs by vacuum hot pressing in a cylindrical die with pressure applied to both ends. The sintered log was furnace cooled at KBI and received a proprietary programmed heat treatment at Brush Wellman. Neither

processing sequence produces a fully annealed structure. The ingot sheet beryllium was made by an established process involving hot rolling a canned beryllium ingot followed by decanning and warm rolling the unjacketed beryllium.⁽⁶⁾ The final bare rolling steps involve 12 pct. reduction at 725°C. The rolled sheet is annealed at 770°C for 5 hr. This anneal does not produce a fully annealed structure either. Additional heat treating cycles for the beryllium tested are given in Table III. (All heat treatments were performed on tensile bars after machining.) The heat treatments (except the grain growth anneals) were selected largely on the basis of an investigation of yield points in beryllium by Floyd.⁽⁷⁾ The solutionizing treatments are designed to dissolve the major soluble impurity, Fe, and retain it in solution with a rapid cool. (The shorter time and lower temperature used for ingot material was used to reduce grain growth.) The rapid cooling is believed to generate new dislocations around insoluble precipitates (primarily BeO) because of thermal stresses during cooling.^(8,9) The solutionize and age treatment favors precipitation of compounds of the type Al Fe Be₄, which removes Fe from solid solution in the matrix.⁽¹⁰⁾ The slow cool following aging reduces the generation of new dislocations from thermal stresses. The two direct aging treatments favor precipitation of Al Fe Be₄, with the fast cool generating fresh dislocations. The strain aging treatment allows the possibility of precipitation at freshly generated dislocations. The grain growth anneals in the ingot source beryllium were designed to evaluate the effect of grain size, with other parameters constant.

of the acoustic emission data was obtained from tensile tests of loaded, sheet-type specimens. The tensile sample geometries are in Figure 2. One acoustic emission transducer was located on gage length for all tests. Some samples were machined with an grip section (Figure 2a) so that an additional transducer be mounted on the grip section and the effect of transducer on evaluated. Compression tests were performed on samples of cross section 3.8 cm. long by 1.3 cm. wide. All powder source samples were machined with the tensile (or compressive) axis transverse to hot pressing direction. Ingot sheet samples with tensile axes parallel (longitudinal) and transverse to the final rolling direction were tested. Mechanical tests were performed on a universal testing machine, generally at the slowest crosshead speed- 0.05 mm/min (.002 in/min). Strains were calculated from the load time curve, with testing machine deformation subtracted. All samples were etched approximately 0.005 inches on all surfaces to remove machining damage. The grip pinholes of all tensile bars were preloaded in compression to approximately twice the expected fracture load to reduce or eliminate acoustic emission from the pinhole regions during tensile testing.

Metallographic samples prepared from strained and unstrained specimens were mechanically polished conventionally, except that the final polishing was performed with a 0.06 μ m alumina slurry in 0.5% HF - water solution. (This final attack polish, or some similar etch-polish procedure, has been shown necessary to reveal cleaved grains.)⁽¹¹⁾

Results

Emission Type

Burst type acoustic emission was observed in all tests. Typical bursts are shown in Figure 3. No change in background (continuous) emission was observed, using the transient recorder, with strain or with any other variable studied. The appropriate measures of acoustic emission were determined to be burst rate and average energy per burst as functions of strain. The RMS acoustic emission output voltage is quantitatively related in a complicated way to the burst rate (effectively a measure of the duty cycle) and energy per burst (related to signal amplitude). RMS increased as expected with increasing burst rate and average energy per burst. The effect of a change in strain rate was to change the burst rate by the same factor while leaving the average energy per burst unchanged. A plot of the relation between burst rate and strain rate changes is given in Figure 4. The ratio plotted as the ordinate in Figure 4 will have the value one if the burst rate change is proportional to strain rate change.

If the burst rate exceeds roughly 400,000 burst/min, the Digital Envelope Processor and Energy Module begin to fail to resolve individual bursts. Some samples exhibited burst rates substantially higher than this over a portion of the stress strain curve at the standard crosshead speed of 0.05 mm/min. Tests of such samples on a different testing machine capable of slower speeds confirmed the emission remained of the burst type at the highest burst rates and provided a measure of the maximum burst rates achieved.

Visual examination of the bursts during the tests indicated no large changes in the frequency of oscillation within the bursts or in the ringdown time as a function of strain or other variables. No detailed frequency analysis was done on the bursts.

Preliminary Tests

Some plastic flow is anticipated in the transition region between the gage section and grip sections of a tensile bar during the course of a tensile test. Because acoustic emission is strongly dependent on strain, emission from the transition region could seriously alter the shape of the acoustic emission versus strain curve. Samples of the type shown in Figure 2a, but with a 1/8 inch radius in the transition region, were tested to estimate the magnitude of this effect. The volume of material for the samples with 1/8 inch radius in the transition region which yields during a tensile test should be about half that for the 1/4 inch radius samples. Differences in the emission behavior between the two types of samples were small; therefore yielding in the transition region does not make a major contribution to the acoustic emission observed for the standard tensile samples (Figure 2).

The transducer was usually located on the gage section. For a transducer located on the extended grip section, the measured burst rate versus strain was qualitatively the same but quantitatively smaller than from a transducer on the grip section. The elastic wave amplitudes are reduced (primarily by wave spreading) upon passing into the larger grip section, and the gage length is thus the best location for the transducer for maximum sensitivity.

The burst rate and energy per burst versus strain measured using a higher frequency S750 transducer (resonant frequency ≈ 750 KHz) were qualitatively similar to those measured using the S140 transducer normally used. The magnitudes, however, were lower which indicates that the sensitivity to acoustic emission bursts is greater in the 100-300 KHz range than at higher frequencies for these beryllium samples.

The contribution to the measured acoustic emission from testing machine noise was negligible. This was confirmed by the reloads for Kaiser effect measurements. During these reloads of the strained tensile bars, which had not been removed from the machine, no emission was detected until close to the stress from which the sample had been unloaded.

Tensile Results

Acoustic emission versus strain is plotted for an as received Brush-Wellman tensile bar in Figure 5 and an as received ingot sheet tensile bar in Figure 6. The principle features are a burst rate peak (BRI) at roughly 0.1% plastic strain, a second burst rate peak (BRII) at roughly 1% plastic strain, and an energy per burst peak (E/B) close to the 0.2% plastic strain yield point. The magnitudes and strains at which the peaks occurred averaged for all the samples of a particular type are given in

Table IV. The results for as received KBI material are from 11 samples taken from 8 different hot pressings, the Brush-Wellman data are from 4 samples out of 3 different pressings, and the ingot samples are from 4 samples (3 longitudinal, 1 transverse) each from a different sheet. An estimate of the variations between pressings and from different samples within the same pressing is given by the standard deviations for the peaks in the as received KBI beryllium listed in Table V. The variation from pressing to pressing is much larger than sample to sample variation within a given pressing, indicating that there are real differences between pressings. The magnitude of BRI correlated well with the tendency toward a yield point in the KBI material. Samples with a yield plateau or a small yield point had very high maximum burst rates compared to samples which showed no indications of a yield point.

The magnitudes and strains at which the acoustic emission peaks occurred after the heat treatments employed are also listed in Table IV. Heat treated ingot beryllium did not generally exhibit a well defined E/B peak, rather it behaved as shown in Figure 7. The magnitude of the E/B peak listed for this condition is the energy per burst at 0.2% plastic strain.

The Kaiser effect is observed in beryllium at room temperature; that is, if a sample is loaded to some stress beyond the onset of plastic flow, unloaded, and then reloaded, no (or very little) acoustic emission will

be observed until the previously achieved stress is reached. After the original stress is achieved, the acoustic emission returns to the values it would have attained in the absence of the unload-load cycle. Duke and Kline have presented evidence that if the surface layer in brass and aluminum is removed by etching before reloading, then substantial emission will be observed during reloading.⁽¹²⁾ Our tests showed no such effect in beryllium. The behavior of a sample with multiple unload-reload cycles with and without intermediate etching is shown in Figure 8. (The sample pinholes were preloaded after etching.)

The general characteristics of the first burst rate peak are that it is sharp (the plastic strain width at half maximum is typically 0.1-0.2 pct.), its magnitude is sensitive to heat treatment and differs greatly between samples from the three sources and it is strongest in samples with a yield point. The second burst rate peak is relatively broad (the strain width at half maximum is typically ~1 pct.) and its location and magnitude are relatively unaffected by heat treatment or by the source of the beryllium. The magnitude of the energy per burst peak is increased by the solutionizing anneal and is relatively unaffected by other thermal treatments. All three peaks can be eliminated by cold work (Kaiser effect), and appear (at least in ingot beryllium) to be independent of grain size.

Compression Tests

The emission behavior in compression was qualitatively similar to that in tension. The magnitudes of the three acoustic emission peaks are given for the compression samples in the last line of Table IV.

The magnitudes of the peaks appear to be substantially smaller in the compression tests, but the difference can be accounted for by specimen geometry as will be discussed later. Corrected for specimen geometry, the acoustic emission from the beryllium in tension and compression are similar.

Discussion

There are a number of possible mechanisms for the origin of acoustic emission in beryllium. Dislocation motion, twinning, grain cleavage, precipitate fracturing or decohesion, and crack propagation are all potential sources. James and Carpenter have investigated possible dislocation mechanisms and concluded that the burst rate is proportional to the rate of change of the mobile dislocation density.⁽¹³⁾ An acoustic emission burst is therefore generated by the breakaway or generation of a substantial number of dislocations, and their subsequent motion over a short time interval. James and Carpenter propose an avalanche mechanism for the nearly simultaneous breakaway or generation of many dislocations. The breakaway or generation of one or a few dislocations produces a small stress wave which triggers breakaway of additional nearby dislocations. In this way, a sufficient amount of dislocation activity can occur in

a short time to generate a detectable stress pulse. The number of dislocations involved is not well established. James and Carpenter estimate 5×10^3 cm of dislocation line are involved in an average burst in their experiments, and Agarwal, et al., calculate that motion of $\sim 5 \times 10^{-3}$ cm of dislocation would produce a detectable pulse.⁽¹⁴⁾

All the experimental evidence is consistent with a dislocation mechanism being responsible for the first burst rate peak. Specifically, the response of the magnitude of the peak to heat treatment agrees with the mechanism proposed by Floyd⁽⁷⁾ for the origin of yield points in beryllium. He proposed that the mechanism responsible is pinning of dislocations by precipitates (probably Al Fe Be₄) rather than Cottrell atmospheres. The precipitate pinning is strong and reduces the mobile dislocation density. When the beryllium is stressed, new mobile dislocations must be generated. If the stress required to move the dislocations is less than that required to generate them, a yield point can occur as proposed by Hahn.⁽¹⁵⁾ If the height of the first burst rate is proportional to the amount of dislocation activity occurring in this way, then the heat treatments should affect the peak height as follows: (1) the solutionized condition should exhibit the lowest burst rate (with the possible exception of the strain aged samples) because of the low Al Fe Be₄ precipitate density and the many glissile dislocations generated during the rapid cool, (2) the solutionized and aged condition should have a relative strong burst rate peak, (3) of the two direct aging treatments, the one with the slow cool

should have a stronger peak because of glissile dislocations generated during rapid cooling, and (4) the strain aged samples will have a large peak if precipitation occurs at the aging temperature or a very low or nonexistent peak if the temperature is too low.

All these predictions are verified by the behavior of the powder source beryllium from both suppliers. The reason for the lack of a burst rate one peak in the solutionized and aged ingot beryllium is uncertain. The iron and aluminum contents (and ratio) are similar to the powder material. Floyd⁽⁷⁾ found the yield point disappeared in powder source beryllium as the grain size increased. Since the magnitude of the first burst rate peak strongly correlates with the tendency toward a yield point, the larger grain size in ingot beryllium may be responsible for the small or missing burst rate one peak. The magnitude of the first burst rate peak in the as received material will depend on the mechanical and thermal processing. Hot pressing, typically near 1050°C, followed by slow cooling as in the KBI material should result in a low mobile dislocation density and therefore a large burst rate peak. The correlation of the burst rate peak with the tendency for a yield point supports this view. Apparently the proprietary Brush-Wellman heat treatment following hot pressing produces a structure with more unpinned dislocations.

The magnitudes of the first burst rate peaks in tensile and compression samples differ by roughly a factor of ten. This difference can be attributed to specimen geometry. A drop of dilute HF - water solution

was placed on one surface of a tensile bar or a compression sample and the transducer attached to the opposite side. The bubbles formed by the reaction of the acid with the beryllium were observed with a microscope and their size just prior to bursting measured. The energy of the bubble bursts was measured with the acoustic emission apparatus in the same way as normal acoustic emission measurements. For the same size bubbles, the apparent energy per bubble burst for the tensile bar was 10 times that for the compression sample. The average energy per burst measured in the tensile bars during mechanical testing was 7.5 times that measured in compression samples, in reasonable agreement with this simple calibration. Reduction in the signal level will reduce the amplitude of many bursts to the noise level; the exact reduction in the measured burst rate will depend on the details of the amplitude distribution but it is likely to be proportional to the reduction in amplitude. Thus burst rate and energy per burst differences between tensile and compressive tests are associated with specimen geometry, and the actual acoustic emission behavior is similar. This result also supports dislocation mechanisms for the observed acoustic emission.

Grain cleavage and crack propagation can be eliminated as contributors to the acoustic emission at low strains by the results of the compression tests, since these phenomena do not occur to a significant extent at low strains in compression. Twinning and precipitate fracturing are

unlikely to be significant at the low strain where the first burst rate occurs, and in any event their frequency of occurrence is unlikely to respond to heat treatment in the same way as the first burst rate peak. Thus the only plausible mechanism for the first burst rate peak is dislocation breakaway from precipitates or the generation of new dislocations.

Evidence for the origin of the second burst rate peak and the energy per burst peak is less conclusive. The second burst rate peak is unlikely to arise from precipitate fracturing or decohesion because the peak is of about the same magnitude in both ingot and powder source beryllium, but the precipitate density (mainly BeO) is much larger in powder source material. Our metallographic results and other available evidence indicates that the twin and cleaved grain density increase monotonically toward the fracture strain, and there is no evidence for a peak in twinning or grain cleavage at around 1% plastic strain. The energy per burst for crack propagation⁽¹⁶⁾ is much larger than any values obtained here, and stable crack growth in beryllium tensile samples at strains well below the fracture strain has never been observed. The peak cannot be associated with burst rate peak-one type activity in the transition region between the gage and grip sections because the second burst rate peak occurs in samples which show no peak one. One plausible explanation is that the second burst rate peak arises from dislocation breakaway from tangles formed by plastic

flow, or generation of new dislocations from different sources at the higher stress corresponding to 1% plastic strain. The energy per burst for bursts in peak 1 and peak 2 are similar, which supports similar breakaway or generation mechanisms.

The situation regarding the origin of the energy per burst peak at about the yield strain is similar to the second burst rate peak. The similarity of the peak in tension and compression is good evidence for a dislocation mechanism. The increased burst size may result from breakaway from stronger or more widely spaced pins.

It should be noted that if acoustic emission is used to monitor proof tests of beryllium structures, substantial acoustic activity may be generated in the absence of any flaws. Depending on the previous treatment or source of the beryllium, substantial emission may be observed at stresses below 15 KSI. Stresses of this magnitude are commonly attained in proof tests, if only in regions of stress concentration or residual stress. There is no evidence that the dislocation activity responsible for this emission is in any way harmful to the performance of the structure. If the structure contains a growing flaw, the acoustic emission from the flaw will be superimposed upon the emission from dislocation activity. A separation of the two effects may be possible since the energy per burst from a growing flaw will generally differ from the activity due to plastic flow. Such a separation has been achieved in at least one instance.⁽¹⁷⁾

Conclusions

The acoustic emission from beryllium from different suppliers and subjected to various heat treatments has been measured. The evidence supports dislocation breakaway or generation of the type proposed by James and Carpenter as being responsible for the observed acoustic emission.

TABLE I

AVERAGE CHEMISTRY AND MECHANICAL PROPERTIES OF POWDER SOURCE BERYLLIUM

<u>Specification</u>		<u>Average Observed</u>	
		<u>KBI</u>	<u>Brush-Wellman</u>
Be	>98.0%	99.1%	98.8%
BeO	< 1.5%	0.82%	1.31%
Al *	< 0.07%	0.045%	0.043%
Fe *	< 0.12%	0.117%	0.101%
Fe/Al		2.6	2.3
C	< 0.10%	0.057%	0.089%
Mg	< 0.08%	0.004%	0.013%
Si	< 0.08%	0.027%	0.024%
All Others, each	< 0.04%		
0.2% Yield Strength	25-38 KSI	29.6 KSI (T)**	31.9 KSI (T)
UTS	>35 KSI	46.1 KSI (T)	50.1 KSI (T)
Elongation (Transverse)	> 2%	3.9 (T)	3.7 (T)
Grain Size	<35 μm	18.7 μm	19.6 μm

*In addition to these maximum values, the Fe/Al ratio is controlled by requiring the Fe and Al contents to fall within the shaded area of Figure 1.

** (T) Testing direction transverse (normal) to pressing direction.

TABLE II

AVERAGE CHEMISTRY AND MECHANICAL PROPERTIES OF INGOT SOURCE BERYLLIUM

BeO		<0.005%
Al		0.067%
Fe		0.143%
Fe/Al		2.1
C		0.080%
Mg		<0.001%
Si		0.056%
0.2% Yield Strength	(L)	27.1 KSI
	(T)	26.4 KSI
UTS	(L)	49.2 KSI
	(T)	42.5 KSI
Elongation	(L)	5.3%
	(T)	4.2%
Grain Size		34 μ m

TABLE III
HEAT TREATMENTS STUDIED

A. Powder Source Beryllium

1. Solutionize - 6 hr. at 1040°C, fast (air) cool.
2. Solutionize and age - 6 hr. at 1040°C, air cool. Age 6 hr. at 760°C, cool at 75°C/hr.
3. Solutionize and strain age - 6 hr. at 1040°C, air cool. Strain 2%, anneal 1 hr. at 400°C, cool at 25°C/hr.
4. Direct age - 6 hr. at 800°C, air cool.
5. Direct age - 6 hr. at 760°C, cool at 75°C/hr.

B. Ingot Source Beryllium

1. Solutionize - 4 hr. at 900°C, fast (air) cool.
2. Solutionize and age - 4 hr. at 900°C, air cool. Age 6 hr. at 760°C, cool at 75°C/hr.

C. Grain Growth Anneals (Ingot Source Beryllium)

1. Anneal - 5 min. at 900°C, air cool.
2. Anneal - 15 min. at 900°C, air cool.
3. Anneal - 30 min. at 900°C, air cool.
4. Anneal - 75 min. at 900°C, air cool.
5. Anneal - 152 min. at 900°C, air cool.

TABLE IV

AVERAGE PROPERTIES OF ACOUSTIC EMISSION PEAKS

Heat Treatment	Material	Burst Rate I		Burst Rate II		Energy/Burst	
		Magnitude (Bursts/Min.)	Strain (Pct.)	Magnitude (Bursts/Min.)	Strain (Pct.)	Magnitude (Relative Units)	Strain (Pct.)
As Received	KBI	>500,000	0.10	14,100	1.0	-	-
	B-W	55,000	0.11	6,900	1.2	14	0.31
	Ingot-L	8,400	0.15	5,300	1.1	}	0.72
	Ingot-T	2,640	0.13	9,000	1.0		
Solutionize	KBI	2,700	0.04	7,600	0.97	63	0.16
	B-W	31,500	0.09	5,500	1.3	22	0.33
	Ingot-L	-	-	14,000	0.6	}	-
	Ingot-T	-	-	34,000	0.52		
Solutionize and Age	KBI	26,000	0.05	8,400	1.0	22	0.23
	B-W	370,000	0.08	5,000	1.2	10	0.46
	Ingot-L	-	-	5,200	0.57	}	-
	Ingot-T	-	-	14,000	0.43		
Solutionize + Strain Age	KBI	-	-	560	1.4	-	-
	B-W	4,900	0.05	1,700	1.3	10	0.08
Direct Age Fast Cool	KBI	19,000	0.04	9,200	0.89	18	0.19
	B-W	15,900	0.11	6,100	1.1	10	0.26
Direct Age Slow Cool	KBI	93,000	0.05	10,000	0.92	15	0.29
	B-W	42,000	0.09	6,900	1.1	13	0.30
Grain Growth 5 Min.-62 μ m	Ingot-L	360	0.01	3,100	1.1	}	0.54
	Ingot-T	780	0.08	6,100	1.1		
Grain Growth 15 Min.-73 μ m	Ingot-L	-	-	4,000	1.0	}	21*
	Ingot-T	-	-	10,000	0.7		
Grain Growth 30 Min.-93 μ m	Ingot-L	-	-	5,900	0.83	}	23*
	Ingot-T	-	-	10,000	0.63		
Grain Growth 75 Min.-107 μ m	Ingot-L	-	-	4,000	0.62	}	21*
	Ingot-T	-	-	12,000	0.63		
Grain Growth 152 Min.-106 μ m	Ingot-L	-	-	5,000	0.57	24*	-
Compression Sample	KBI	46,000	0.06	2,100	1.1	4	0.2

*No well defined energy per burst peak, reported value is at yield strain. See text.

TABLE V
STANDARD DEVIATION FOR AS RECEIVED ACOUSTIC
EMISSION BURST RATE PEAKS

	<u>Burst Rate I</u>		<u>Burst Rate II</u>	
	<u>Magnitude</u> <u>(Bursts/Min.)</u>	<u>Strain</u> <u>(Pct.)</u>	<u>Magnitude</u> <u>(Bursts/Min.)</u>	<u>Strain</u> <u>(Pct.)</u>
Value	>500,000	0.10	14,100	1.02
Standard Deviation All Samples	*	0.04	6,300	0.07
Standard Deviation Multiple Samples, One Pressing	*	0.05	530	0.03

*Maximum burst rate could not be measured on many samples at the normal strain rates.

FIG 1

ACCEPTABLE Fe AND Al CONTENTS
FOR P 31664 BERYLLIUM (SHADED AREA)

(a)

(b)

FIG 2

TENSILE BAR GEOMETRIES: (a) POWDER SOURCE BERYLLIUM - EXTENDED GRIP SECTION FOR SOME SAMPLES SHOWN DOTTED, AND (b) INGOT SOURCE BERYLLIUM.

FIGURE 153. Oscilloscope trace from the transient recorder of typical burst emissions. (Vertical: 2 volts per centimetre. Horizontal: total time 1000 microseconds.)

FIG 4

FIG. 5

FIG. 6

FIG 7

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